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(54) **High tension DC voltage generating apparatus.**

(57) A high tension DC voltage generating apparatus includes a transformer (6) having a primary winding (7) to which an AC voltage is supplied and *n* secondary windings (8_1 – 8_n), and first and second rectifier circuits (13 and 14) each containing (n+1) (13_1 – 13_{n+1} : 14_1 – 14_{n+1}) which are connected in series in the same direction of polarity and are correspondingly arranged to form a plurality of stages of diode pairs (13_1 and 14_1 – 13_{n+1} and 14_{n+1}). The diode pairs (13_1 and 14_1; 13_{n+1} and 14_{n+1}) of the first and last stages are interconnected at the cathodes and the anodes, respectively. The secondary windings are connected between the anodes of the diode pairs except between the diode pairs (13_{n+1}, 14_{n+1}) of the last stage, while being arranged with the polarities alternately reversed.

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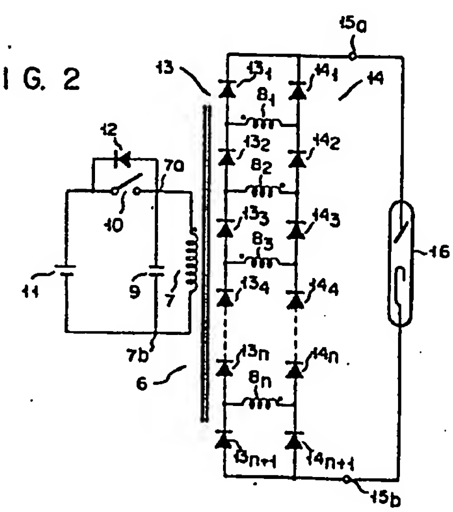

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High tension DC voltage generating apparatus

This invention relates to a high tension DC voltage generating apparatus, and more particularly to a high tension DC voltage generating apparatus suitable for the supply of high tension DC voltage to an X-ray emitting apparatus.

In general, a high tension DC voltage generating apparatus for supplying a high tension DC voltage to an X-ray emitting apparatus contains a transformer by which a commercial AC voltage or an AC voltage of several hundred Hz is stepped up to a 50 to 400 KV high tension voltage and a rectifier circuit by which the stepped up high tension AC voltage is converted into a high tension DC voltage. This high tension DC voltage is applied between the anode and the cathode of the X-ray tube of the X-ray emitting apparatus through a high voltage cable. In general, the transformer can be made smaller in size when a high frequency power is supplied thereto. Therefore, an AC power supply source which includes a high frequency inverter which invertes a DC voltage to an AC voltage is used for the transformer. However, since the transformer has a magnetic core made of a silicon steel plate, the cutoff frequency thereof is limited to a maximum of several hundred Hz. In order to increase the cutoff frequency of this transformer to more than several hundred Hz, in a home use television set, the secondary winding of the transformer is

divided into several windings and the secondary windings are connected in series with diodes inserted therebetween to obtain a required high tension voltage. Since such a high tension voltage generating apparatus allows a distributed capacitance of a transformer viewed from the primary winding side of the transformer and leakage inductance well to be decreased, the cutoff frequency of the transformer can be increased. The high tension DC voltage generating apparatus employed in the home use television set is so arranged that the DC voltage is obtained by rectifying the AC voltage by the diodes. Therefore, this DC generating apparatus can not be used for the X-ray emitting apparatus for the following reasons. The level of the DC voltage to be applied to the X-ray tube of the X-ray emitting apparatus must be at least 10 times that applied to the Braun tube of the television set. This results in the increase of the number of the secondary windings of the transformer and the number of diodes coupled to the secondary windings as well. The Braun tube of the television set serves as a light load for a DC voltage source and the capacitance of the anode of the Braun tube is great. Therefore, a peak value of the half wave rectified voltage is supplied to the anode of the Braun tube as a DC voltage. Accordingly, a half wave rectifier system can be adopted for the rectifier circuit in the home use television receiver. However, in the high tension DC voltage generating apparatus for applying a high DC voltage to the X-ray tube, the load capacity of the X-ray tube is approximately 1,000 times that of the Braun tube. As a result, the sum of the anode capacitance of the X-ray tube and the capacitance of the high tension cable for transmitting the rectified power is not sufficient to keep the half wave rectified voltage at the peak value thereof. For this reason, the AC voltage of each of the secondary windings of the transformer must be full-wave rectified

with those rectified DC voltages are added together to obtain a desired high tension voltage.

Fig. 1 shows an example of a conventional high tension DC voltage generating apparatus suitable for the supply of the DC high tension voltage to the X-ray tube. In Fig. 1, an AC voltage at a given frequency is applied across the input terminals of the primary winding 1a. This transformer 1 has n secondary windings 2_1, 2_2, ..., 2_n. The symbol "." indicates the polarity of each winding at a time point. Each secondary winding is connected with four diodes with the polarity as shown. The DC voltages each obtained by the combination of one secondary winding and the associated four diodes 3, are combined to provide a desired high tension DC voltage for application between the anode 4a and cathode 4b of the X-ray tube 4.

The high tension DC voltage generating apparatus shown in Fig. 1, however, has the following defects. Four diodes are used for each secondary winding, so that a great number of diodes are required for constructing the apparatus. Further, it makes the arrangement of the rectifier circuit complicated as a whole.

Accordingly, an object of the present invention is to provide a high tension DC voltage generating apparatus which can provide full-wave rectified DC voltage from each of the secondary windings of a transformer by connecting a couple of rectifier elements to each of the secondary windings, and supply a desired high tension DC voltage to a load with a high load capacity.

According to the present invention, there is provided a high tension DC voltage generating apparatus comprising a transformer having a primary winding connected to an AC power supply source and a plurality of secondary windings, a first rectifier circuit having a plurality of rectifier elements connected in series in the same direction of polarity, a second rectifier circuit having a plurality of rectifier elements

connected in the same manner and direction as the plurality of rectifier elements in the first rectifier circuit, the plurality of rectifier elements in the first and second rectifier circuits being correspondingly arranged one-to-one to form rectifier element pairs of a first to (n+1)th stages, a positive load terminal connected to the cathodes of the rectifier element pair of the first stage, a negative load terminal connected to the anodes of the rectifier element pair of the (n+1)th stage, each of the secondary windings being connected between the anodes of a corresponding rectifier element pair except the rectifier element pair of the (n+1)th stage, with polarities alternately reversed.

This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

Fig. 1 shows a connection diagram of a conventional high tension DC voltage generating apparatus in conjunction with an X-ray tube;

Fig. 2 shows a connection diagram of a high tension DC voltage generating apparatus according to this invention, when it is applied to an X-ray tube; and

Fig. 3 shows waveforms useful in explaining the operation of the AC power supply source in Fig. 2.

As shown in Fig. 2, a transformer 6 contains a primary winding 7 and a plurality of secondary windings 8_1, 8_2, ..., 8_n. The black dots attached to the windings indicates the voltage polarity induced in the windings at a given time. A DC power supply source 11 is connected between the terminals 7a and 7b of the primary winding through a switching element 10 and a resonant capacitor 9 is connected across the input terminals 7a and 7b. A dumper diode 12, connected at the cathode to one end of the DC power supply source 11, is connected between the terminals of the switching

element 10. The resonant capacitor 9, the switching element 10 and the dumper diode 12 cooperatively form a voltage resonant type single ended switching circuit. Specifically, this switching circuit applies an AC voltage between the input terminals 7a and 7b of the primary winding 7 by being opened and closed periodically. The characteristic impedance $Z_0 = \sqrt{L/C}$ is preferably set to a value between 0.5 ohms and 500 ohms, when the inductance of the primary winding 7 and the capacitance of the capacitor 9 are denoted by L and C, respectively. Further, the ratio T_{on}/T of the turn on period T_{on} to one cycle switching period T of the switching element 10 is set to a value between 0.05 and 0.5. The high tension DC voltage generating apparatus of this invention further contains a first rectifier circuit 13 having a plurality of rectifier elements such as diodes 13_1 - 13_{n+1}, connected in series between positive and negative load terminals 15a and 15b in the same direction of polarity and a second rectifier circuit 14 having a plurality of diodes 14_1 - 14_{n+1} also connected in the same manner and direction as those of the first rectifier circuit. Those diodes 13_1 - 13_{n+1} and 14_1 - 14_{n+1} in the first and second rectifier circuits 13 and 14 are correspondingly arranged to form diode pairs 13_1 and 14_1 - 13_{n+1} and 14_{n+1} corresponding to a first to (n+1)th stages. The diode pair 13_1 and 14_1 of the first stage are connected at the cathodes to the positive load terminal 15a. The diode pair 13_{n+1} and 14_{n+1} of the (n+1)th stage are connected at the anodes to the negative load terminal 15b. A first secondary winding 8_1 connects the anodes of the diode pair 13_1 and 14_1 of the first stage. A second secondary winding 8_2 connects the anodes of the diode pair 13_2 and 14_2 of the second stage, with an opposite polarity to that of the first secondary winding 8_1. Further, a third secondary winding 8_3 connects the anodes of the diode

pair 13_3 and 14_3 of the third stage with a polarity which is opposite to that of the secondary winding 8_2 but is the same as that of the first secondary winding 8_1. In this way, the subsequent secondary windings connect the anodes of the correspondng diode pairs respectively. The $\underline{n}$ th secondary winding 8_n connects the anodes of the diode pair 13_n and 14_n of the $\underline{n}$ th stage. The polarities of the first to $\underline{n}$ th secondary windings 8_1 to 8_n are alternately reversed in succession. An X-ray tube 16, serving as a load for the first and second rectifier circuits 13 and 14, is connected at the anode to the positive load terminal 15a and at the cathode to the negative load terminal 15b.

The operation of the AC power supply source of Fig. 2 will be described referring to waveform diagram of Fig. 3.

When a switching pulse as shown in Fig. 3(a) is applied to a control terminal of switching element 10, switching element 10 is periodically turned on. Since ON resistance of switching element 10 is selected to be sufficiently smaller than the impedance of primary winding 7, current i_c flows through primary winding 7 and switching element 10 during the ON state of switching element 10 which, as shown in Fig. 3b, linearly increases from t_s to t_o. Switching element 10 is forcibly turned off during a short period between t_o to t_{on} so that the current i_c rapidly decays to zero. After the current i_c becomes zero, current i_L of primary winding 7 still continues its flow into resonant capacitor 9 and a stray capacitor of the switching element 10, as shown in Fig. 3(c), due to inertia of the primary winding 7. Because resonant capacitor 9 has a larger capacitance than the stray capacitance the current flows mainly through the resonant capacitor 9. Thereafter, the resonant current, changing with cosine curve, flows through primary winding 7 during a period t_{on} to t_d, as shown

in Fig. 3(c). On the other hand, the voltage V_c across switching element 10, rises the moment the resonant current starts to flow through the resonant capacitor 9, while tracing sine curve during a period t_{on} to t_f, as shown in Fig. 3(d). The rising slope of the voltage V_C is more gentle than that in the absence of resonant capacitor 9. Therefore, at a point of time $t = t_o$ when switching element 10 is turned off, the waveform of the current i_c flowing through switching element 10 never overlaps with the waveform of the voltage V_c across the switching element 10. Even if those waveforms overlaps each other, the overlapping area of the waveforms will be fairly small because the rising slope of the voltage V_c is gentle as mentioned above. In other words, the power dissipation of the switching element is remarkably reduced.

After time t_f, the voltage V_c will go negative but it is kept zero since damper diode 12 conducts. The damper current i_D decreasingly flows during a period t_f to t_d, as shown in Fig. 3(e). At time point t_d, the next succeeding switching pulse is applied to switching element 10, so that the above-mentioned operation is repeated. During the period in which the damper current i_D flows, the voltage V_c across switching element 10 is zero and therefore the waveforms i_c and V_c never overlap each other at the time point t_d that switching element 10 is subsequently turned on.

The AC voltage which is applied across the terminals 7a and 7b is obtained by subtracting the input voltage E_{in} from the voltage V_c across the switching element 10 as shown in Fig. 3(f).

During the period that a positive voltage is applied to the terminal 7a of the primary winding 7, that is, the period when a positive voltage is applied to the black dotted terminals of the secondary windings, those diodes 13_{n+1}, 14_n, ..., 14_4, 13_3,

14_2 and 13_1 forwardly biased by the positive voltage applied, rectify the voltages in the secondary windings. And the rectified voltages are summed and the summed total is applied as a desired high tension DC voltage across the load terminals 15a and 15b. During the period that a negative voltage is applied to the primary winding 7, positive voltages are induced in the non-black dotted terminals of the secondary windings. The positive induced voltages forwardly bias the diode 14_{n+1}, 13_n, ..., 13_4, 14_3, 13_2 and 14_1 to rectify the voltages in the secondary windings. The rectified voltages are combined to form a high tension DC voltage which in turn is applied between the load terminals 15a and 15b. The voltages induced in the secondary windings are full-wave rectified by a couple of diodes.

As described above, according to the present invention, by merely coupling a couple of diodes with each of the secondary windings, the voltages in the secondary windings can be full-wave rectified respectively. Therefore, the number of the diodes is considerably reduced, and further, the wiring means of the rectifier circuits is considerably simplified, when compared with the prior art which uses four diodes for each secondary winding. The fact leads to low cost manufacture and high reliability of the high tension DC voltage generating apparatus. The circuit arrangement according to this invention allows the number of the secondary windings to be readily increased for increasing the output DC voltage. Further, a high tension DC voltage having a predetermined peak value can be applied to a load without using the capacitance associated with the load and the high tension cable since the high tension DC voltage has the full wave rectified wave form. For the above reasons, the high tension DC voltage generating apparatus according to the present invention is suitable for

driving an X-ray tube.

It was empirically proved that the apparatus has a better rise characteristic of the high tension DC voltage applied between the positive and negative load terminals 15a and 15b than the prior apparatus of Fig. 1. This indicates that the apparatus according to the present invention can supply a high electrical energy to an X-ray tube for a shorter period. This feature implies that the apparatus according to the invention is well suitable for driving an X-ray tube which is turned on and off 20 times or more per second.

It is evident that the usual AC power supply source can be directly coupled with the primary winding 7. Nevertheless, it is preferable to use an AC power supply source with the voltage resonant type single ended switching circuit as shown in Fig. 2, for the reason that the switching circuit can cause the transformer 6 to be made small in size owing to a less switching loss and a high frequency signal having several KHz to 20 KHz to be transmitted thesethrough with good efficiency. In a conventional single ended switching circuit, only an output having a single polarity can be obtained from the switching circuit. In this case, even if the conventional single ended switching circuit is coupled to a transformer which is coupled at the secondary side thereof to a full wave rectifier, the full wave rectifier operates only when the output from the switching circuit has the above-mentioned single polarity. In the voltage resonant type single ended switching circuit, an output having positive and negative polarities is obtained by utilizing an electrical energy stored in the primary winding of the transformer and in the resonant capacitor. Thus, the high tension DC voltage generating apparatus including a voltage resonant type single ended switching circuit connected to a transformer and a full wave rectifier circuit connected

to the transformer can elevate the transmission efficiency of a power about twice times that of the conventional high tension DC voltage generating apparatus.

Claims:

1. A high tension DC voltage generating apparatus characterized by comprising:

a transformer (6) having a primary winding (7) connected to an AC power supply source and a plurality of secondary windings (8_1 - 8_n);

a first rectifier circuit (13) having a plurality of rectifier elements (13_1 - 13_{n+1}) connected in series in the same direction of polarity;

a second rectifier circuit (14) having a plurality of rectifier elements (14_1 - 14_{n+1}) connected in the same manner and direction as the plurality of rectifier elements in said first rectifier circuit, the plurality of rectifier elements in said first and second rectifier circuits being correspondingly arranged one-to-one to form rectifier element pairs (13_1 and 14_1, ..., 13_{n+1} and 14_{n+1}) of a first to (n+1)th stages;

a positive load terminal (15a) connected to the cathodes of the rectifier element pair (13_1 and 14_1) of said first stage;

a negative load terminal (15b) connected to the anodes of the rectifier element pair (13_{n+1} and 14_{n+1}) of said (n+1)th stage;

each of said secondary windings being connected between the anodes of a corresponding rectifier element pair except between the rectifier element pair of said (n+1)th stage, with polarities alternately reversed.

2. A high tension DC voltage generating apparatus according to claim 1, characterized in that said AC power supply source comprises a DC power supply source (11) connected at one end to one end (7a) of said primary winding (7) through a switching element (10) which is periodically turned on and off, and at the other end to the other end (7b) of said primary winding (7); a resonant capacitor (9) connected across said primary winding; and a dumper diode (12) connected at the anode

to said one end (7a) of said primary winding and at the cathode to said one end of said DC power supply source.

3. A high tension DC voltage generating apparatus according to claim 2, characterized in that a characteric impedance ranges from 0.5 to 500 ohms, said characteric impedance (Z_O) being defined to be equal to the square root of a ratio (L/C) of the inductance (L) of said primary winding (7) to the capacitance (C) of said resonant capacitor (9); and

a ratio of the turn on period (T_{on}) to one cycle of the switching period (T) of said switching element (10) ranges from 0.05 to 0.5.

4. A high tension DC voltage generating apparatus according to claim 1, characterized in that said positive and negative load terminals (15a, 15b) are connected to the anode and cathode terminals of an X-ray tube, respectively.

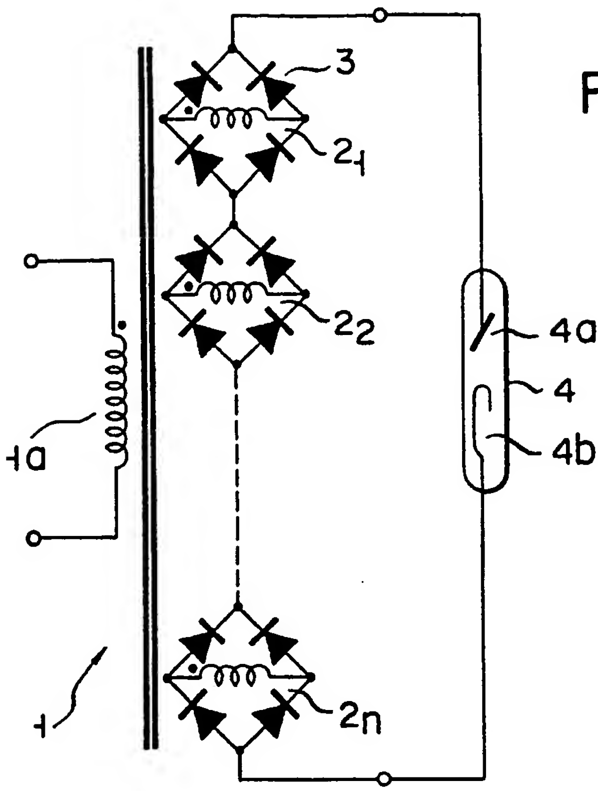

3
2_1
2_2
2_n
1a
1
4a
4
4b

FIG. 1

FIG. 2

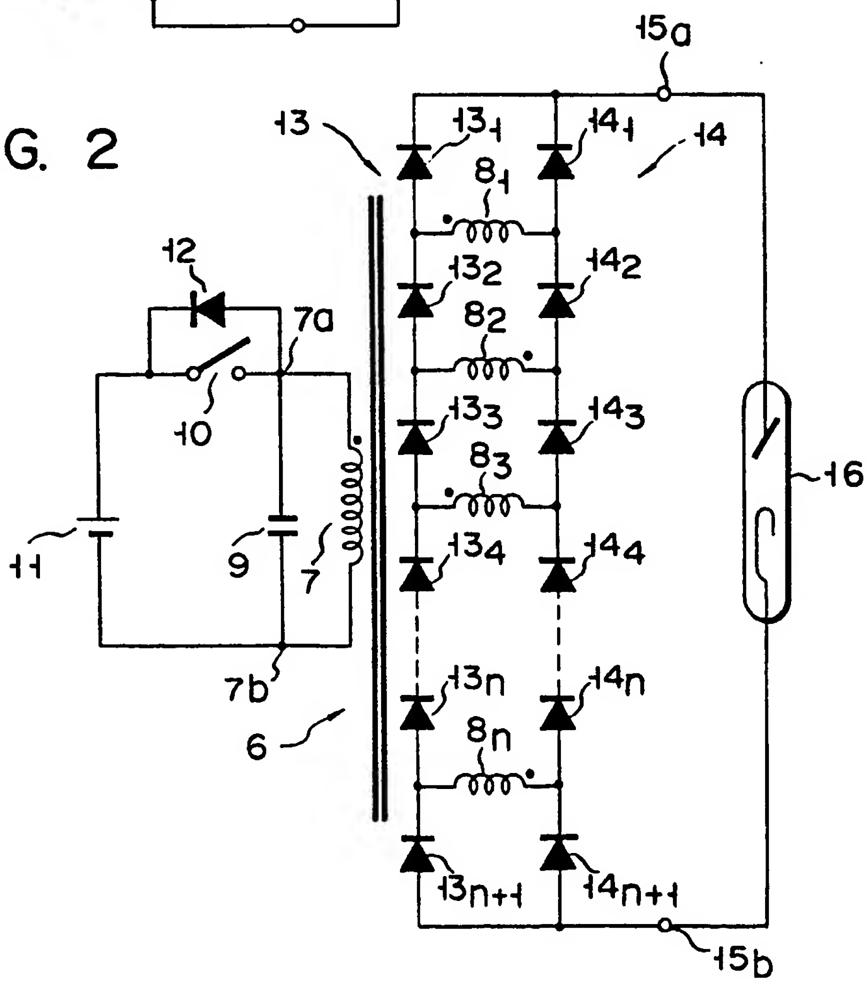
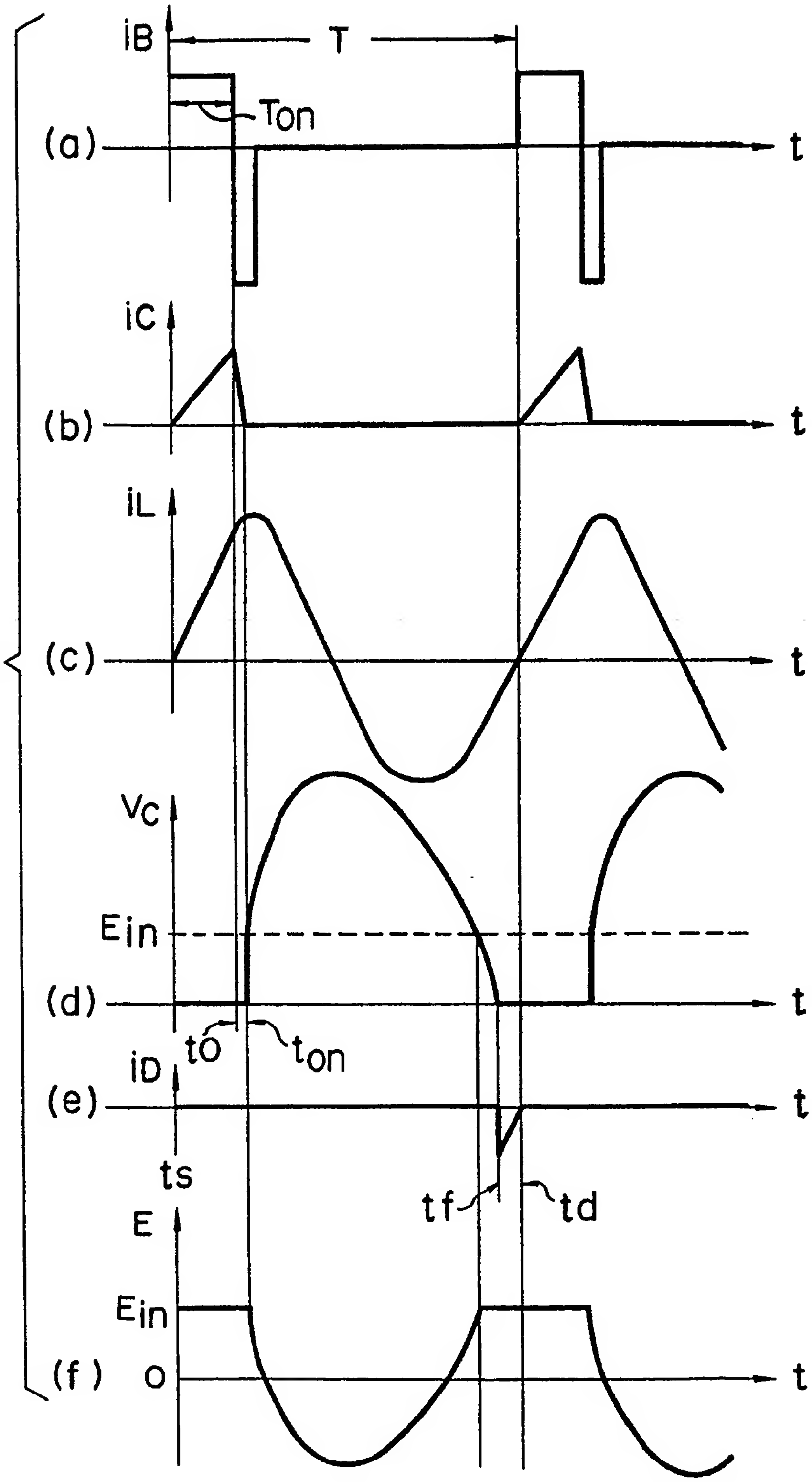

15a
13
13_1
14_1
14
8_1
12
13_2
14_2
8_2
7a
10
13_3
14_3
8_3
16
11
9
7
13_4
14_4
7b
6
13_n
14_n
8_n
13_{n+1}
14_{n+1}
15b

FIG. 3



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EUROPEAN SEARCH REPORT

Application number

EP 83 30 5089

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
X	Patent Abstracts of Japan vol. 6, no. 140, 29 July 1982 & JP-A-57-65272	1,2	H 05 G 1/20 H 02 M 7/10

X	US-A-3 419 786 (M.D. BRANE) * Column 2, lines 24-59; figures 2, 3 *	1	

TECHNICAL FIELDS SEARCHED (Int. Cl. 3)

H 02 M 7/00
H 05 G 1/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	07-12-1983	GESSNER E A F

CATEGORY OF CITED DOCUMENTS

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